A&A manuscript no.
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03(11.01.2 ; 13.07.2)

ASTRONOMY
AND
ASTROPHYSICS
1.2.2008

CGRO, Radio and Optical Observations of The Quasar NRAO 140

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Received 1995 ; accepted

Abstract. We report on Compton Gamma Ray Observatory (CGRO), radio and optical observations of the radio-loud, superluminal quasar NRAO 140. The source is not detected (significance 3σ) by any of the CGRO instruments OSSE, Comptel and EGRET. Radio observations simultaneous to the OSSE observation and optical monitoring over three-monthly intervals show no signs of extraordinary behaviour when compared to previous observations. We demonstrate that the CGRO non-detections do not require a spectral break at hard X-rays, but can be explained by a steep spectrum in the MeV range comparable to that of 3C 273.

Key words: Galaxies: active ; Gamma rays: observations

1. Introduction

EGRET has detected $\approx$ 50 blazars at MeV and GeV energies (v. Montigny et al. 1995a). It is generally believed that this emission originates in collimated outflows and is enhanced by relativistic beaming. Many of these objects show apparent superluminal motion. However, not all superluminal sources with flat radio spectra have been detected yet (v. Montigny et al. 1995b). This may be due to either intrinsic physical reasons preventing the production of MeV γ-rays or their escape from the emission region, geometrical conditions such as misalignment or bending of the jet, or these sources may have been missed due to their variability, i.e. EGRET has only observed them in their low states. Since duty cycles of EGRET-detected blazars have a wide range (Heidt & Wagner 1995, Wagner and Witzel 1995), this is a viable possibility to explain that many superluminal sources have not yet been detected at γ-ray energies.

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To address this question, observations at energies of several tens to hundreds of keV may provide new insights, e.g. if a spectral break at these energies is detected. OSSE observations of this class of sources may provide insight into this issue. A number of blazars have already been detected by this instrument (McNaron-Brown et al. 1995). While most of the blazars observed so far by OSSE have been observed following their detection by EGRET, we follow a different approach and try to identify suitable candidates by their X-ray brightness.

One of the most prominent of these unseen superluminal sources is the quasar NRAO 140 (Marscher and Broderick 1982), located at a redshift of z=1.258. This object is known for its brightness in X-rays (e.g. Marscher 1988, Ohashi et al. 1992) and its hard X-ray spectrum. Observations with EXOSAT (Marscher 1988), Ginga (Ohashi et al. 1992) and ASCA (Turner et al. 1995) have found power law spectra with photon indices of α=1.6-1.7. No evidence for spectral hardening above $\approx$ 10 keV, indicative for the presence of a Compton reflected component, was found in the Ginga data. Extrapolating the EXOSAT, Ginga and ASCA spectra to the OSSE energy range ($>$ 50 keV), a positive detection was considered likely (see also Fig. 1). The observation of apparent superluminal motion made the object a good candidate for a Comptel or EGRET detection.

2. Observations and Results

2.1. GRO observations

CGRO consists of four instruments which span the γ-ray range from 20 keV to 20 GeV: BATSE, an uncollimated burst monitor (energy range $>$ 20 keV, Fishman et al. 1989); OSSE, a collimated phoswich type detector (50 keV - 10 MeV, Johnson et al. 1993), and the imaging instruments Comptel (0.75-30 MeV, Schönfelder et al. 1993) and

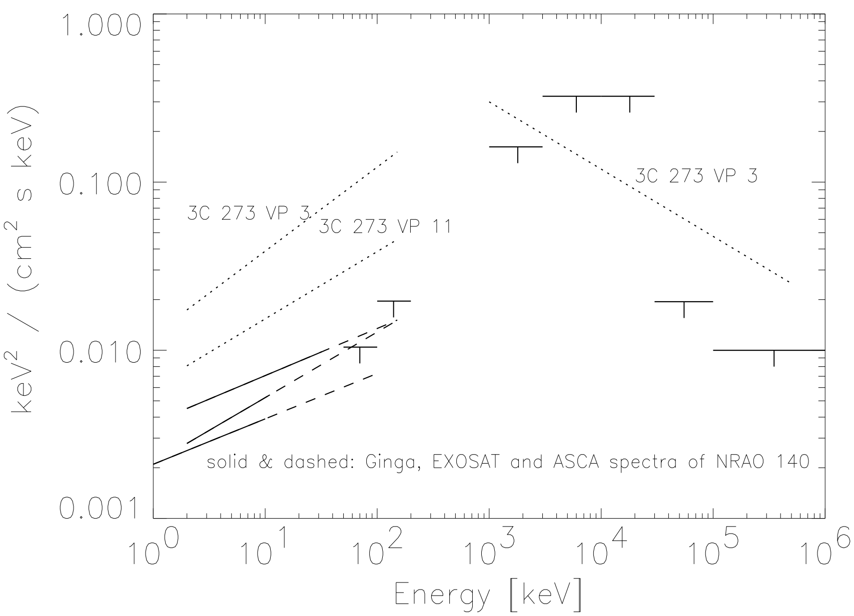

Fig. 1. NRAO 140 Upper Limits vs. fluxes observed from 3C 273. Solid lines and dashed extensions show the EXOSAT and Ginga spectra of NRAO 140 and their extrapolations into the OSSE range. Dotted lines represent the 3C 273 spectra from VPs 3 and 8/11. Upper limits (2σ) represent NRAO 140 during the observations reported here.

EGRET (50 MeV-30 GeV, Thompson et al. 1993). The latter three have been designed to observe point sources.

In the course of this investigation, NRAO 140 was observed by OSSE during 1994 May 10-24 (Viewing Period [VP] 326, 327), and by Comptel and EGRET during 1994 Apr 26 - May 10 (VP 325). The source was not detected by any of these instruments. For the OSSE observation, the 2σ upper limit in the 50-150 keV range is 2.13×10^{-3} photons / (cm^2 s MeV) for a net observation time of 465 ksec. This is just below the extrapolation of the Ginga spectrum, and compatible with the extrapolation of the EXOSAT and ASCA spectra. Contrary to non-detections of many Seyfert galaxies, the non-detection of NRAO 140 therefore does not require a spectral break at ≈ 100 keV. The EGRET upper limit from VP 325 (1.3×10^{-7} photons / (cm^2 s) @ > 100 MeV, 2σ) is comparable to that derived from several observations in Phase I (Fichtel et al 1994.) The Comptel upper limit could be improved by adding all available observations of NRAO 140 at various times.

2.2. Radio and Optical Observations

NRAO 140 was observed by the Effelsberg telescope during the OSSE observations in 1994 May 15-19 at 5 GHz. The observations at higher frequencies – namely 8.41 GHz – were carried out within a period of 10 days after the OSSE observations (Table 1). The measurements consisted of cross-scans (azimuth/elevation) through the source position. Corrections for gain and elevation effects were applied using standard calibrator sources (e. g. NGC7027, 3C 286). The absolute calibration was performed according to Baars et al. (1987). The flux densities were comparable to earlier observations (≈ 2 Jy, Table 1). An energy index $\alpha^5_{8.4} = 0.2$ (S $\sim \nu^{-\alpha}$) was calculated. Recent observations give a value of $\alpha^5_{8.4} = 0.3$ for 3C 273, similar to NRAO 140.

Table 1. Effelsberg Observations

Date	Flux [Jy]	Error
5.0 GHz		
1994 May 15	1.96	0.03
1994 May 16	1.81	0.03
1994 May 17	1.94	0.03
1994 Jun 06	1.94	0.03
6.0 GHz		
1994 May 19	1.78	0.03
8.41 GHz		
1994 May 27	1.71	0.05
1994 May 28	1.74	0.05
1994 Sep 24	1.75	0.05

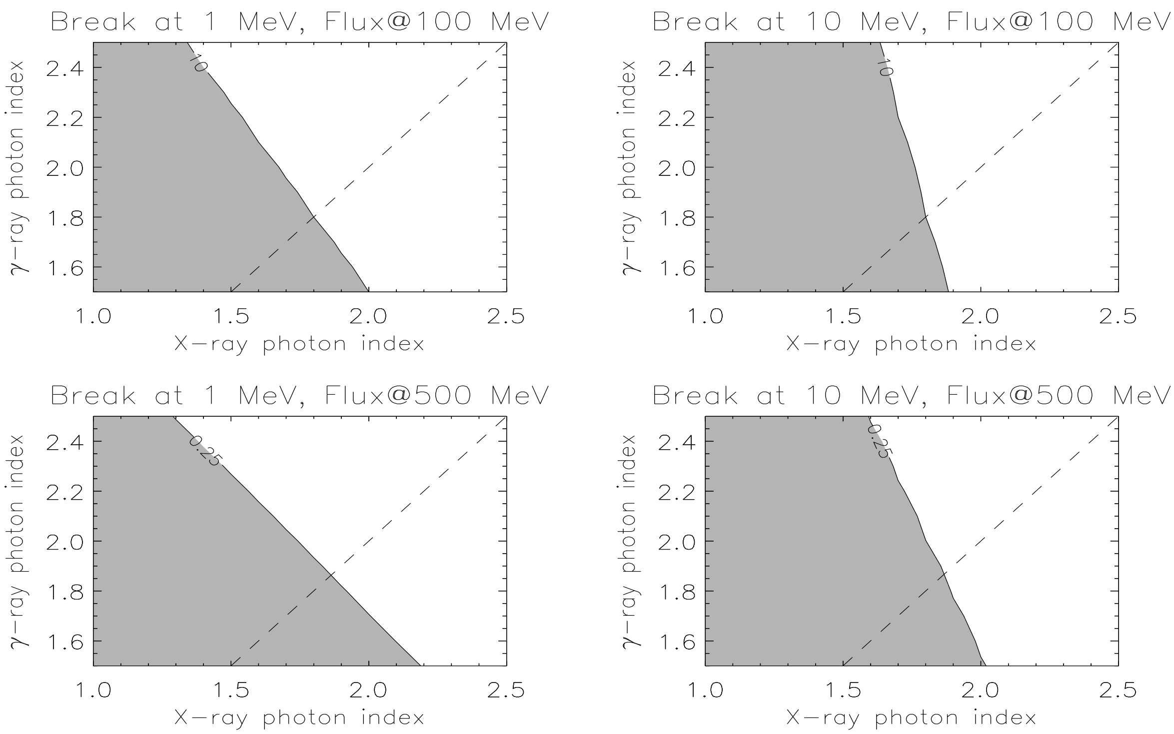

Fig. 2. Combinations of X-ray and γ-ray indices leading to an EGRET detection extrapolating typical ROSAT blazar fluxes ($10^{-3} photons/(cm^2\ s\ keV)$ at 1 keV) to the EGRET energy range, assuming breaks at 1 or 10 MeV. Contours correspond to label values times $10^{-7} photons/(cm^2\ s\ GeV)$, the detection sensitivities of EGRET at 100 and 500 MeV for a two-week observation . Dashed lines show $\alpha_x = \alpha_\gamma$. Combinations to the left of the contours (shaded areas) result in detection

Relative photometry was performed at the Landessternwarte Heidelberg (see Table 2). A CCD attached to a 70 cm telescope was used for observations in the R-band (680nm). Individual epochs were tied together using non-variable field stars. In spite of the slight variations there is no indication of unusual activity. Both the average level as well as the scatter are typical for NRAO 140.

Table 2. Relative Photometry at LSW

Average: 17.42 ± 0.12		
Date	R Mag.	Error
1994 Mar 03	+0.13	0.03
1994 Mar 28	-0.12	0.02
1994 Mar 29	-0.11	0.02
1994 Jul 05	-0.02	0.06
1994 Sep 19	+0.12	0.02

3. Discussion

3.1. NRAO 140

In Fig. 1, we compare the CGRO upper limits of NRAO 140 to data of 3C 273 (Johnson et al. 1995, v. Montigny et al. 1993). The dotted lines show the spectrum of 3C 273 during June 1991 (VP 3) measured by OSSE, Comptel and EGRET October 1991 (VP 8 and 11, OSSE; VP 11 Comptel and EGRET). During October 1991, 3C 273 was about a factor of 3 less bright in the OSSE range than in VP 3. At that time, it was not detected by Comptel and EGRET (Williams et al. 1995). The Comptel and EGRET upper limits for that observation of 3C 273 were comparable to the levels of NRAO 140. An X-ray/γ-ray spectrum similar to that of 3C 273 from VP 3, scaled by a factor of 5 or 10 to match the observed X-ray fluxes of NRAO 140, is compatible with the upper limits for NRAO 140 observed by CGRO. We conclude that for NRAO 140 a spectral break $\approx$ 100 keV is not required to explain the OSSE non-detection. Considering that OSSE has detected only about one third of the blazars that it has observed (McNaron-Brown et al. 1995), this indicates that OSSE detections even of bright blazars may only be feasible in a high state of emission. Furthermore, the Comptel and EGRET non-detections are also compatible with a 3C 273 type spectrum.

3.2. Other undetected superluminal sources

v. Montigny et al. (1995b) have discussed the possible reasons for the non-detection of a number of prominent superluminal sources by EGRET. They consider variability and physical reasons such as misaligned jets or opacity. The proton initiated cascade model of Mannheim (1992) predicts that the proton to electron ratio governs the magnitude of gamma-ray emission which is low when the proton to electron ratio is close to or lower than 1. We adopt a phenomenological approach: the distribution of observed photon indices in the EGRET range shows that 3C 273 has one of the steepest spectra (α_γ=2.4) observed by EGRET so far, and, following the example of NRAO 140, we argue that sources with steep X-ray and γ-ray spectra and relatively low fluxes may fall below the EGRET sensitivity limit. To estimate whether this is a realistic assumption, we use known X-ray fluxes and broad-band high energy spectra of flat spectrum radio-loud quasars. Analysis of ROSAT archival data of blazars show that the observed 1 keV fluxes of these objects cluster around 10^{-3} photons/ (cm^2 s keV), with the exception of 3C 273, which is about a factor of 10 brighter. The distribution of ROSAT X-ray photon indices shows a scatter around a mean value of ≈ 2. We extrapolate power law spectra with indices similar to those observed by ROSAT from 1 keV to energies of 1 or 10 MeV, where CGRO observations indicate that a break in the blazar spectra must be located (e.g. McNaron-Brown et al. 1995), and continue the extrapolation with a range of γ-ray indices broader than observed by EGRET to energies of several 100 MeV. We find that even if the X-ray spectrum is as hard as α_x=1.5, a detection by EGRET becomes more and more unlikely as the gamma-ray photon index becomes steeper than α_γ=2, unless the X-ray intensity increases by at least an order of magnitude, which is more than observed between the low and high states of 3C 279 (Maraschi et al. 1994). This effect is shown in Fig.2. Steep γ ray spectra may thus be responsible for the non-detection at MeV/GeV energies of several blazars showing apparent superluminal motion. For NRAO 140, the X-ray flux and spectral index (I_{1keV}=1.78$\times$ 10^{-3} photons / (cm^2 s keV) in the observer's frame, α_x=1.73) reported by Turner et al. (1995) implies that the gamma-ray spectrum must be steeper than α_γ=2.4 for a break energy of 10 MeV to give a flux below the EGRET detection threshold. For a break energy of 1 MeV, the non-detection requires $\alpha_\gamma < 2.1$.

However, six out of nine of the superluminal sources in the sample presented in von Montigny et al. (1995a) have EGRET spectra steeper than α_γ=2. If we assume that the spectra of these sources do not change even during a γ-ray flare, this high detection rate indicates that a significant part of the EGRET sources either have a hard X-ray spectrum, or a spectral break occurs at energies higher than 1-10 MeV as derived by McNaron-Brown et al. (1995).

4. Summary

NRAO 140 has not been detected by any of the instruments on CGRO despite being considered a good candidate due to its X-ray brightness, hard X-ray spectrum and apparent superluminal motion. We argue that the source may have an X-ray/γ-ray spectrum similar to 3C 273, but is not detected since it is about 10 times dimmer than 3C 273. Accordingly, we conclude the non-detection of many superluminal sources may be due to their steep gamma-ray spectra and low break energies, not necessarily their hypothetical inactivity. 3C 34.47, which has similar properties as NRAO 140 (Ohashi et al. 1992) and has also not yet been detected by EGRET (v. Montigny et al. 1995b), may be another typical example. High-sensitivity observations at hard X-rays with XTE and SAX can help to address this issue in the future.

Acknowledgements. MM acknowledges the support at MPE during the Comptel and EGRET data analysis, especially from W. Collmar and H.D. Radecke. We thank A. Kraus for discussion and data reduction of the radio data. This work was supported by DARA grant 50 OR 92054.

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